EXPERIMENTAL STUDY OF DARRIEUS TURBINES IN CONFINED FREE-SURFACE FLOWS

L. Kara Mostefa[1*], L. Chatellier[1], L. Thomas[1]

[1]Institut PPRIME, UPR3346, CNRS – Université de Poitiers – ISAE-ENSMA, France

*Mohamed.larbi.kara.mostefa@univ-poitiers.fr

Abstract

Both scientific and industrial communities have a growing interest for marine renewable energies. There is a wide variety of technologies in this domain, with different degrees of maturity. Our work focuses on two models of an H-type vertical axis Darrieus (1931) tidal turbine with the objective of studying the effect of fluid-structure interactions on their performances. The experimental studies were carried out on the 15m long and 1m² square section free surface channel of the Environmental Hydrodynamics Platform at PPRIME Institute (Figure 1). The maximum flow discharge through the channel is Q = 500 l/s.

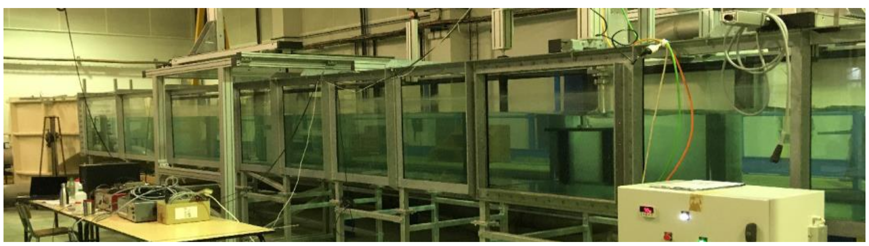
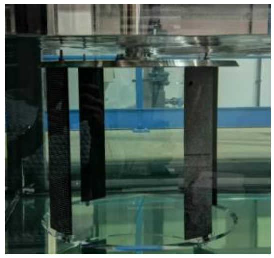
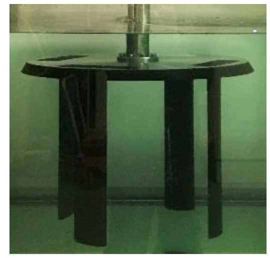


Figure 1: free surface hydrodynamic channel

Two prototypes are used on the experimental studies. The first prototype is a down-scaled model of the one used in the study of Gorle et. al (2016). The prototype is composed of four straight rigid blades maintained by circular flanges on both ends of the rotor (Figure 2a). For this work, we propose a second prototype. It is equipped with free-ended interchangeable blades attached to a single flange (Figure 2b). A configuration of the second prototype mounted with rigid stainless-steel blades are first used for comparison with the dual-flange turbine. A configuration using PEEK blades of significantly lower Young modulus is investigated in order to address the fluid-structure interaction problem.



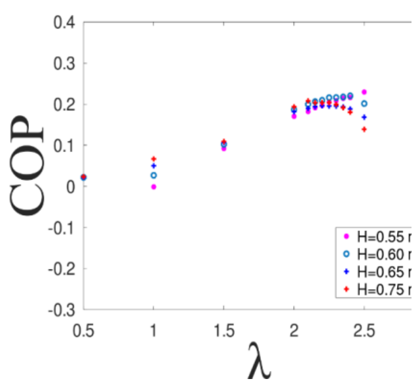
(a)



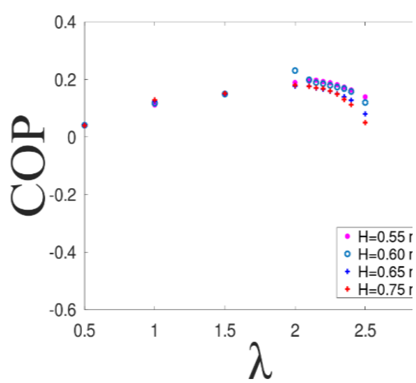
(b)

Figure 2: Dual- (a) and single-flange (b) straight blade H-type Darrieus turbines

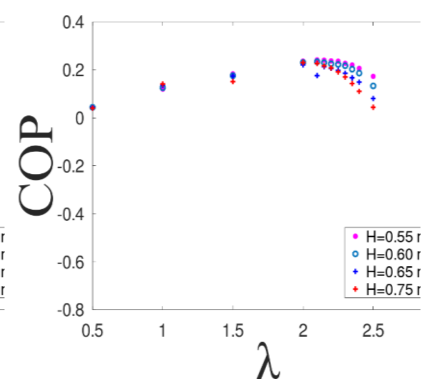
Both turbine models have a rotor diameter of 400mm and 80mm-chord NACA0015 blades of 400m length, their section is A=0.16 m^2. The rotor is driven by a servo motor and equipped with torque and angular position sensors. Torque measurements are first carried out to characterize the performances of the turbines in a range of operating conditions with different combinations of water level *H*, flow discharge *Q* and reduced speed λ. On the first studies, the water level has been varied from 0.55 m to 0.75 m and the flow velocity is fixed to V=0.66 m/s. The results are shown in Figure 2. It can be seen that the water level has little influence on the operation of the turbine and the COP values are relatively close to the tested water level values. The coefficient of performance COP is calculated by the following expression: COP=P/(0.5·ρ·A· V^3)). ρ is the water density defined as 1000kg/m3 and P is the turbine's power.



Prototype 1: Rigid blades and assembly.



Prototype 2: Free-ended stainless steel blades (rigid)



Prototype 3: Free-ended PEEK blades (deformable)

Figure3 : Influence of rigidity, immersion and TSR on the turbine performances

Figure 4 shows the results obtained for a constant water level of H=0.555 m and two flow velocities (V=0.66m/s and 0.909 m/s). As expected, the three types of typical operating regimes in Darrieus turbines are recovered. A first regime for lowest values of tested reduced speed (λ=$\omega R/V$), the blades are subject to intense stalls due to a high blade angle of attack.

This regime is characteristic of the dynamic stall that will be described in the PIV results section. For highest values of tested parameters, the performance of the turbine is limited by the drag generated by its components. The last regime is a transition zone presenting a balance between dynamic and viscous effects. On this transition zone, the best performance is obtained for the Darrieus turbines. For the higher incident speed V=0.909 m/s (Froude number Fr_{II}= 0.36), the best performance of prototype 1 (model Blades and rigid assembly) has been identified for a reduced speed λ=2.25, for a COP=38%. For the prototype 2 and 3, the optimal speed is obtained for a reduced speed λ=2.10 for getting a COP=28%. However, for all tested values of reduced speed, the best performance is obtained by the prototype 1. The COP values of prototype 2 have almost the same behavior than prototype 3.

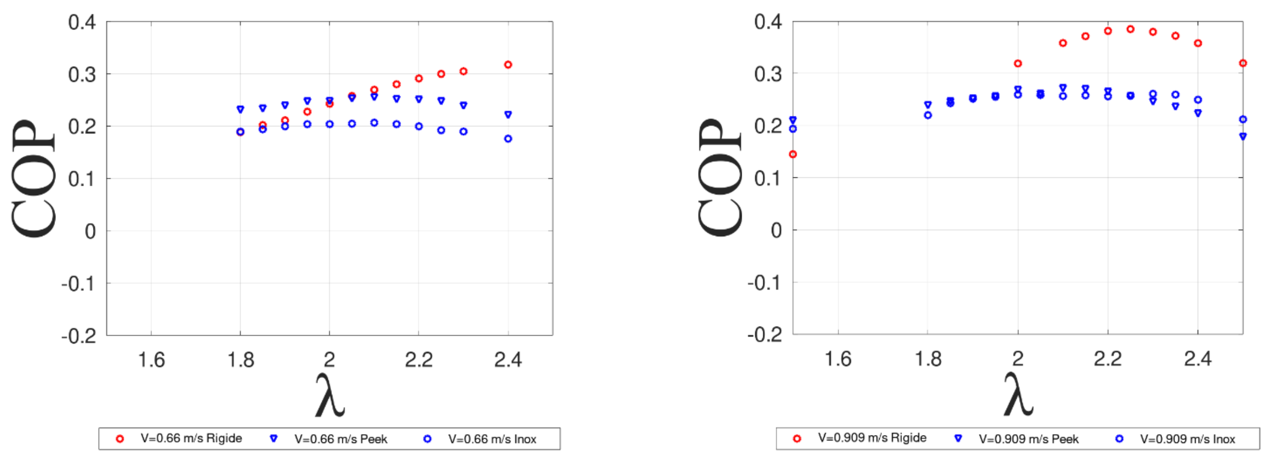


Figure 4: Torque measurement; Influence of the operating regime

The PIV measurements are conducted within the mid-plane of the rotor. Two 200 mJ double-cavity Quantel EverGren, 532nm ND: YAG laser have been used in order to limit the masking of the measurement zone during the passage of the blades (Figure 2a). A LaVision Imager Pro LX 16MP CCD camera is positioned below the glass bed of the channel, imaging a 1200 mm x 800 mm measurement region through a 45° mirror. The PIV timing is adjusted so that successive phase-locked velocity fields correspond to angular displacements of 7.5°, thus guaranteeing a complete coverage of the turbine rotation cycle (figure 6).

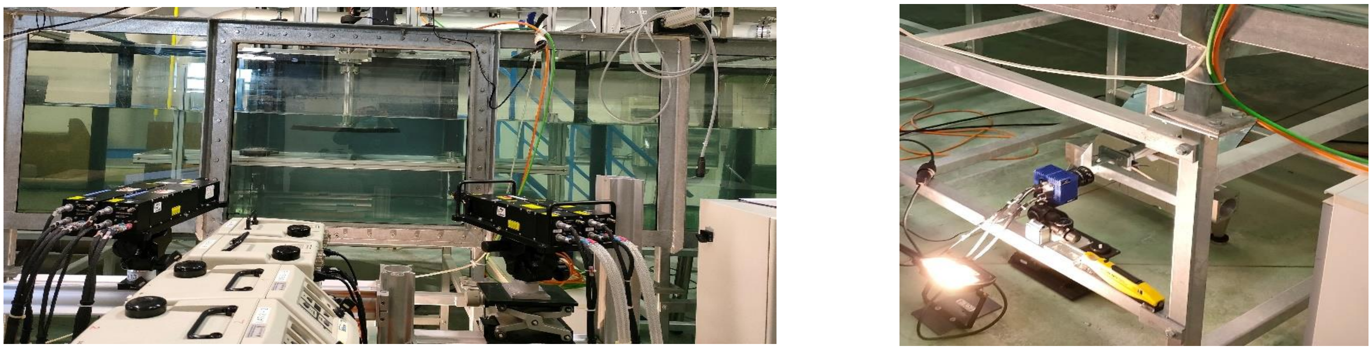


Figure 5: Particle Image Velocimetry apparatus and setup

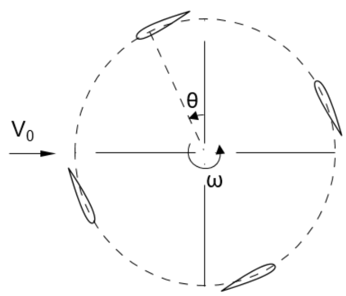
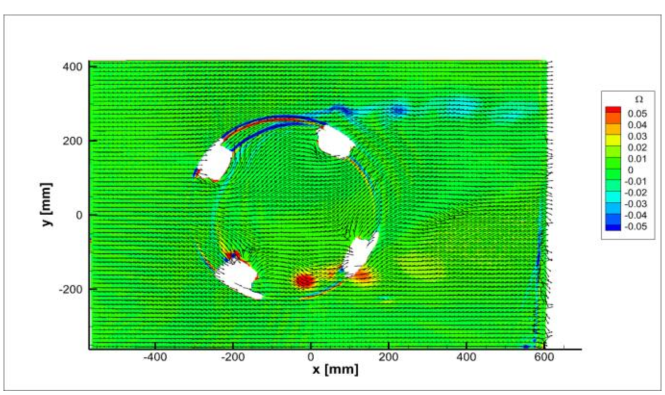
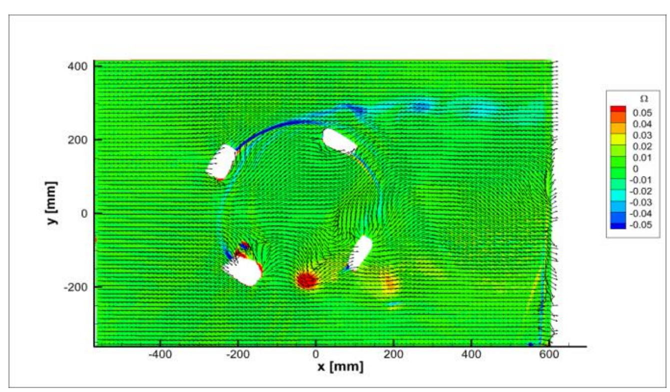


Figure 6 : Illustration the angular positioning of the blades and corresponding global position of turbine θ

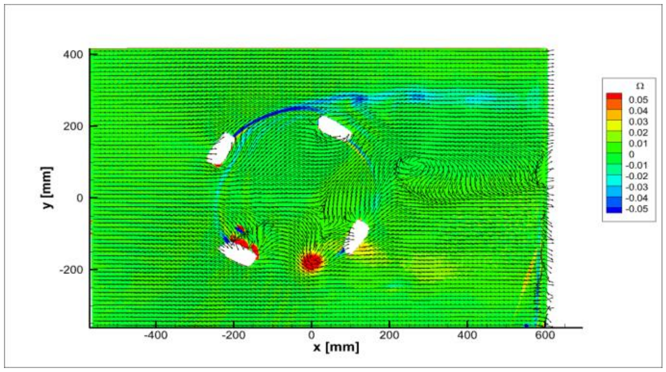
Figure 7 shows the vorticity field for each prototype on their optimal configuration. The same behavior is observed for the three-vorticity fields in which a dynamic stall vortex of positive vorticity is identifiable. A second vortex appears also on the three configurations next to the first vortex. The value of the vorticity on this second vortex depends on the rigidity of the blades. For a rigid blade, as used on the prototype 1, the peak vorticity increases reaches a maximum. The magnitude of the vorticity decreases with decreasing rigidity. Vortex shedding of negative vorticity is also observable in the upper part of the wake.



Prototype 1 : λ =2.25



Prototype 2 : λ=2.10



Prototype 3 : λ=2.10

Figure 7: Phase-averaged vorticity fields

Conclusion

An experimental study has been conducted on 3 versions of a Darrieus turbine with either rigid or flexible assembly and blades. Torque measurements indicate the influence of rigidity, which is materialized in the performance curves of each prototype.

Phsae-locked PIV results show a very satisfactory agreement with and the literature concerning dynamic stall (Bossard et al, 2006). The different experiments carried out on the turbine model allowed us to identify the blade-vortex structure interactions. Which exhibit similar dynamics for the 3 turbine configurations at their optimal operating conditions.

This work will be extended by the study of the dynamics of vortex releases and their interactions with the blades. Tests deformation measurements on free-ended rigid an flexible will be conducted blades in order to characterize their response fluctuating hydrodynamic forces and the influence of their flexibility on the efficiency of the turbine.

References

Darrieus G, Turbine having its rotating shaft transverse to the flow of the current, US Pate nt n°1835018A, 1931

Gorle JMR, Chatellier L, Pons F, Ba M, Flow and performance analysis of H-Darrieus hydroturbine in a confined flow: A computational and experimental study. Journal of Fluids and Structures 2016; 66 :382–402, 2016

Maître T, Bossard J, Vignal L, Franc JP, Darrieus turbine modellings - Comparisons with performance measurements and PIV fields. International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Apr 2016, Honolulu, United States.